Mini-Dome Fresnel Lens Photovoltaic Concentrator Development

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Introduction

Since 1986, our organizations have been actively developing a new high-performance, light-weight space photovoltaic concentrator array [refs. 1-6]. This development work is being done under Small Business Innovation Research (SBIR) contracts funded by NASA and SDIO. The new array is the first space photovoltaic concentrator system to use a refractive optical concentrator in the form of a unique, dome-shaped, point-focus, Fresnel lens [refs. 7-9]. The new array is also the first space photovoltaic concentrator system to utilize prismatic cell covers to eliminate gridline obscuration losses [refs. 10-11]. By combining these new array features with state-of-the-art cell technology, we anticipate substantial improvements over present space power systems in both array power density (watts/square meter) and specific power (watts/kilogram).

The three most critical elements of the new array are the lens, the prismatic cell cover, and the photovoltaic cell. During 1987 and 1988, prototypes of the latter two elements were successfully developed and tested [refs. 5-6]. The prismatic cover has provided cell performance enhancement levels in close agreement with predictions. Likewise, the prism-covered cell performance has matched predictions. In fact, gallium arsenide cells made by Varian have achieved over 24% efficiency (at 100 AM0 suns irradiance and 25C) after prismatic cover application, the highest single-junction space cell efficiency yet measured by NASA Lewis, as we described at the last SPRAT Conference.

Since the last SPRAT Conference, the master tooling required to make the third critical element of the new array, the mini-dome Fresnel lens, was completed. This state-of-the-art diamond-turned tooling was made to ENTECH specifications by 3M Company. During 1989, prototypes of the mini-dome lens optical concentrator have been successfully made from this tooling and tested. Outdoor test results, fully discussed in later paragraphs, confirm that the mini-dome lens will provide excellent optical efficiency levels. In fact, the first prototype flexible silicone rubber lens achieved 86% net optical efficiency.

Also since the last SPRAT Conference, we have also been adapting the prismatic cell cover technology to Boeing's new mechanically stacked multi-junction (MSMJ)

cell, which is fully compatible with the mini-dome lens concentrator approach. Boeing's new cell (fully described in another paper at this SPRAT Conference [ref. 12]) includes a transparent gallium arsenide (GaAs) top cell and a gallium antimonide (GaSb) bottom cell, with both cells using prismatic covers to eliminate gridline obscuration losses. These stacked cells have recently achieved over 30% AM0 efficiency (at 25C and 100 suns irradiance) in simulator testing. This new MSMJ cell technology has excellent long-term implications for the mini-dome lens concentrator array.

The following paragraphs provide an update on the mini-dome lens concentrator array development program.

System Description

Since the mini-dome Fresnel lens concentrator array has been described in previous papers [refs. 1-6], only a brief description of the new concentrator system will be presented here. Figure 1 shows an individual dome lens photovoltaic concentrator module. The square-aperture dome lens focusses sunlight onto a state-of-the-art concentrator cell (i.e., a single-junction gallium arsenide cell or a tandem MSMJ cell). An optically clear silicone rubber prismatic cell cover is bonded to the upper surface of each cell to eliminate gridline obscuration losses. A high-thermal-conductivity dielectric layer is used to bond the cell assembly to the aluminum backplane radiator. Top and bottom electrical contacts are used to join cells into desired series/parallel circuits. The 200 micron thick radiator and the 150 micron thick aluminum honeycomb structure are bonded together to form a rigid assembly, which is coated with a white thermal control coating (with high infrared emittance and low solar absorptance).

Each individual dome lens module provides an operational power output of about 0.4 watt. Multiple modules are integrated into a larger panel, capable of providing tens or hundreds of watts, as shown in Figure 2. The individual dome lenses are placed within the square slots forming the honeycomb, with the top of each lens located below the top of the honeycomb after assembly. Thus, panels can be stacked on top of one another, without touching the lenses, thereby allowing compact stowage of multiple panels. To form multi-kilowatt arrays, the panels have been designed for use with existing automatically deploying space structures, such as the Astro Aerospace extendible support structure (ESS) [ref. 13], as shown in Figure 3. Such structures have been designed for deploying and supporting other space photovoltaic concentrator panels, such as the TRW mini-Cassegrainian concentrator (MCC) [ref. 14]. Due to its higher power density, the dome lens concentrator (DLC) will require a smaller array size than the MCC concentrator, as shown in the lower portion of Figure 3.

Figure 4 shows the ENTECH/Varian GaAs concentrator cell geometry and performance after prismatic cover application. NASA Lewis measured the cell efficiency to be over 24% at 25C and 100 AM0 suns, and about 22% at 100C and 100 AM0 suns.

Similar performance can be expected for a transparent version of the GaAs cell, forming the top cell in a tandem MSMJ assembly, as Boeing will report at this SPRAT Conference [ref. 12]. When a prismatically covered GaSb cell is placed beneath such a transparent GaAs cell, a boost efficiency of about 9% is currently attainable, based on recent simulator measurements for a GaSb cell under a GaAs filter [ref. 12].

Figure 5 shows the baseline mini-dome Fresnel lens configuration. The shape of the lens corresponds to a unique geometry which provides minimal reflection loss for each prism, and thus maximal transmittance for the lens [ref. 7]. Also, this design provides a smaller solar image, smaller optical aberrations, and greatly improved manufacturing tolerances, compared to other concentrator designs [ref. 8]. The lens has a 4.0 cm focal length and a 3.7 cm square aperture (13.7 sq.cm. in area). The lens is designed to focus incident sunlight onto a 0.4 cm diameter cell (0.126 sq.cm. active area), the same size cell as that used in the TRW MCC reflective space concentrator [ref. 14].

The lens irradiance profile can be tailored by selecting the appropriate angle for each of the individual prisms comprising the lens, such that the individual prism images overlap to provide the desired irradiance distribution across the focal plane. For the present lens, the prism angles have been optimized to form an image over a small 0.26 cm diameter circular portion of the cell, to allow the module to tolerate a 1 degree tracking error without appreciable loss in performance [ref. 6]. Figure 6 shows this lens design approach, including the photon flux distribution over the cell with and without a sun-tracking error. To provide this smaller image size, the predicted peak irradiance at the center of the cell is about 400 suns, which is quite tolerable for the cell under consideration [ref. 6]. The predicted optical efficiency of the lens is above 90%, comparable to ENTECH's terrestrial photovoltaic concentrator lenses. The optical efficiency could be further improved by applying anti-reflection coatings to the lens surfaces.

The lens materials have been selected to provide good optical performance, as well as durability in the orbital environment. The ceria-doped microglass superstrate is the same material which has been used for cover slides on one-sun photovoltaic cells in space. The clear silicone RTV substrate is the same material which has been used as an adhesive to bond cover slides to one-sun photovoltaic cells in space. Diamond-turned master tooling, which is used to mold the silicone rubber Fresnel lens, was delivered to ENTECH by 3M Company in late 1988. Prototype silicone rubber lenses have since been successfully made and tested, as highlighted in a later paragraph. Glass superstrate thermal forming experiments have been underway for several months at both ENTECH and outside vendor facilities. While the glass forming appears to be straightforward, the best methods of manufacturing such microglass domes have not yet been selected.

The following paragraphs discuss recent test results on the key components of the mini-dome space photovoltaic concentrator system.

Key Component Test Results

In 1988, NASA Lewis tested several of the latest gallium arsenide cells (made by Varian of Palo Alto, California) under simulated space sunlight, before and after prismatic cover application by ENTECH. Test results (at 100 AM0 suns irradiance and 25C) for one of these cells are shown in Figure 4. The cells utilize a parallel gridline geometry, with grids about 12 microns wide on 127 micron centers. After prismatic covering, the cell efficiency increased about 11%, due principally to a 12% short-circuit current increase. This performance enhancement matches expectations for the prismatic cover in this application. The 24% cell efficiency of Figure 4 is the highest single-junction space cell efficiency measured by NASA Lewis to date. This same prism-covered cell achieved about 22% efficiency at 100 AM0 suns and 100C, the expected operational conditions on orbit for the mini-dome lens array. Thus, prototype cells and prism covers have demonstrated performance levels in close agreement with early predictions [refs. 1-2].

In 1989, Boeing has achieved over 30% AM0 efficiency in simulator tests of their GaAs/GaSb MSMJ cell system, which includes prismatic covers on both the top and bottom cells. This unprecedented efficiency was achieved at 100 AM0 suns irradiance and 25C cell temperature, as fully described in another paper at this conference [ref. 12]. This MSMJ cell is ideally suited for use in the mini-dome lens panel, where it will provide a significant array performance improvement, as discussed in a later paragraph.

During 1989, we have obtained the first test data on the mini-dome Fresnel lens. Prototype silicone rubber lenses, without the microglass superstrates, have been successfully molded. A typical lens is shown in Figure 7, with centimeter graph paper in the background. Figure 8 shows a prototype lens focussing actual sunlight onto a test gallium arsenide cell. This cell is a 1985-vintage Cassegrainian concentrator cell made by Applied Solar Energy Corporation (ASEC) and furnished to ENTECH by NASA Lewis. The cell has a radial gridline pattern, not compatible with the prismatic cover, and a short-circuit current response typical of ASEC cells of that vintage [ref. 15]. The test results reported below were all obtained with the same heat sink-mounted ASEC cell, by measuring its short-circuit current response under three different irradiance conditions: (i) one direct normal sun irradiance; (ii) the full circular aperture dome lens irradiance (Figure 8); and (iii) the masked dome lens irradiance (Figures 9 and 10), which simulated the square aperture of the mini-dome lens discussed in previous paragraphs. The full dome lens has an aperture diameter of about 5.5 cm. Since the lens was made of flexible silicone rubber without the microglass superstrate needed for rigidity, its thickness was increased to about double the 200 micron (8 mil) design value of Figure 5, to make the dome self-supporting. For testing, the dome lens was adhesively bonded to an acrylic sheet, with a hole in the sheet to allow the focussed sunlight to travel from the lens to the cell. The hole was cut with an available saw with a 5.4 cm diameter, slightly smaller than the

full dome lens aperture. Since the hole was smaller than the lens aperture, some ray blockage occurred during the full dome lens testing. For the more important testing, with a 3.7 cm square aperture surrounded by an opaque mask placed in front of the dome lens, ray blockage by the undersized hole was negligible.

Figure 11 summarizes the outdoor test results for the prototype silicone mini-dome Fresnel lens. The data columns of Figure 11 include lens aperture area (two bracketing values for the full dome lens test); cell active area; geometric concentration ratio (GCR), which is the ratio of lens aperture area to cell active area; the cell short-circuit current (ISC); net concentration ratio (NCR), which is the ratio of the ISC produced with the lens in place to the ISC produced at one-sun with only direct normal insolation reaching the cell; and optical efficiency, which is the ratio of NCR to GCR. Note that the full dome lens had a measured optical efficiency between 81% and 85%, depending on whether the gross lens aperture area or the mounting plate hole area is used as the true aperture for the test. More importantly, note that the masked square aperture lens had a measured optical efficiency of 86%.

The measured 86% optical efficiency for the first prototype square-aperture lens is less than the predicted value (>90%) for production lenses. However, the prototype lens was much thicker than production lenses; the prototype lens was self-supporting, rather than rigidized by a microglass superstrate; the lens and cell were hand-aligned with two bolts (Figure 8), rather than precisely aligned with fixtures; and the proto-type was hand-pointed at the sun. We believe that each of these factors contributed to a slight lowering of performance for the prototype lens. Despite these prototype shortcomings, the focal spot produced by the lens on the small cell appeared to match predictions and the measured optical efficiency was a respectable value.

Current Array Development Status

Now that the three key array components have been successfully tested, project activities are now directed toward the fabrication and testing of several multi-module panels during the next few months. These prototype panels will use our baseline design, which includes the key elements summarized in Figure 12. The total mass of the baseline panel equates to about 2.4 kg/sq.m, with most of the panel mass being attributable to the microglass lens superstrate and the aluminum honeycomb/radiator assembly. In addition to this near-term baseline panel, we are also developing a longer-term, ultra-light panel for SDIO applications. The microglass superstrate in the baseline panel is primarily a monatomic oxygen shield for low earth orbit (LEO) applications. In higher orbits, which are of great interest to SDIO, the glass should become unnecessary, since oxygen is no longer present. In addition, the aluminum radiator thickness can be reduced from 200 microns to 50 microns, with only a 30C increase in cell operating temperature, based on conservative thermal analyses. Like-wise, the aluminum honeycomb thickness can be reduced from 150 microns to 50

microns, while still providing adequate stiffness, based on preliminary structural analyses. With only these three changes in design, the panel mass should be reduced from 2.4 kg/sq.m. to about 1.0 kg/sq.m. Pending the successful fabrication and testing of several prototype baseline panels, we will initiate prototype fabrication of the ultralight SDIO panels.

Updated Array Performance Estimates

Figure 13 summarizes our latest performance estimates for the mini-dome Fresnel lens array, based on the recent test results for prototype cells and lenses discussed above. Using measured efficiency values for GaAs cells and mini-dome lenses, the near-term baseline array should provide an on-orbit efficiency of 17%, corresponding to a power density of 230 w/sq.m. As previously discussed, the baseline panel mass is about 2.4 kg/sq.m. The previously described automatically deploying ESS structure has a mass of 0.7 kg/sq.m., when designed to support the relatively heavy TRW MCC concentrator panels [ref. 13]. Adding this value to the panel mass provides an array mass of 3.1 kg/sq.m., which equates to a specific power of 74 w/kg for the baseline array.

The second column of Figure 13 corresponds to the substitution of the Boeing MSMJ cell for the single-junction GaAs cell in the baseline panel. This single change raises the array efficiency to 22%, the corresponding power density to 300 w/sq.m., and the specific power to nearly 100 w/kg. These values are based on a GaSb cell boost efficiency of 8% (at 25C), which was achieved by Boeing earlier this year [ref. 12]. The calculated GaSb boost efficiency at operating temperature is based on an estimated fractional power/temperature coefficient 2.3 times as high as for the GaAs cell, to reflect the correspondingly lower open-circuit voltage of the GaSb cell (i.e., 0.49 volts versus 1.14 volts at 25C and 100 suns).
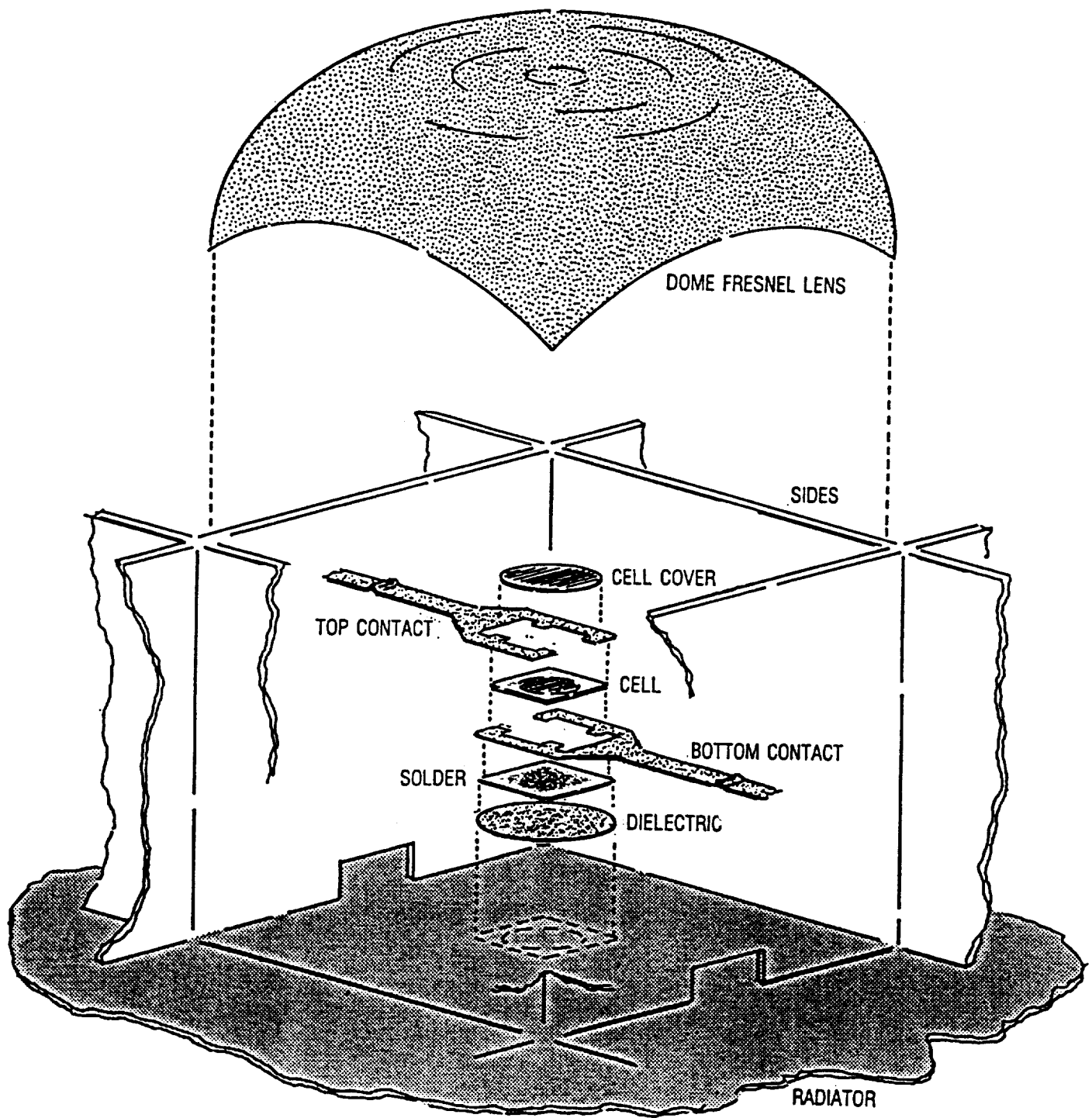
The third column of Figure 13 includes the ultra-light panel mass reductions discussed in a previous paragraph. In addition, the ESS structure mass estimate has been reduced to conservatively include the effect of reduced loads due to the drastically reduced panel mass. Also, a slight improvement in GaSb cell performance is included, since a 9% room-temperature boost efficiency has already been measured for GaAs-filtered cells [ref. 12]. Finally, the lens efficiency is expected to improve to 90% with the application of antireflection coatings to the lens surfaces. These small lens and cell performance gains offset the higher cell operating temperature, to retain the 300 w/sq.m. power density of the previous column. With the drastically reduced mass, the specific power increases to more than 200 w/kg.

In summary, recent prototype cell and lens test results indicate that near-term array performance goals of 300 w/sq.m. and 100 w/kg are feasible, and that a longer-term goal of 200 w/kg is reasonable.

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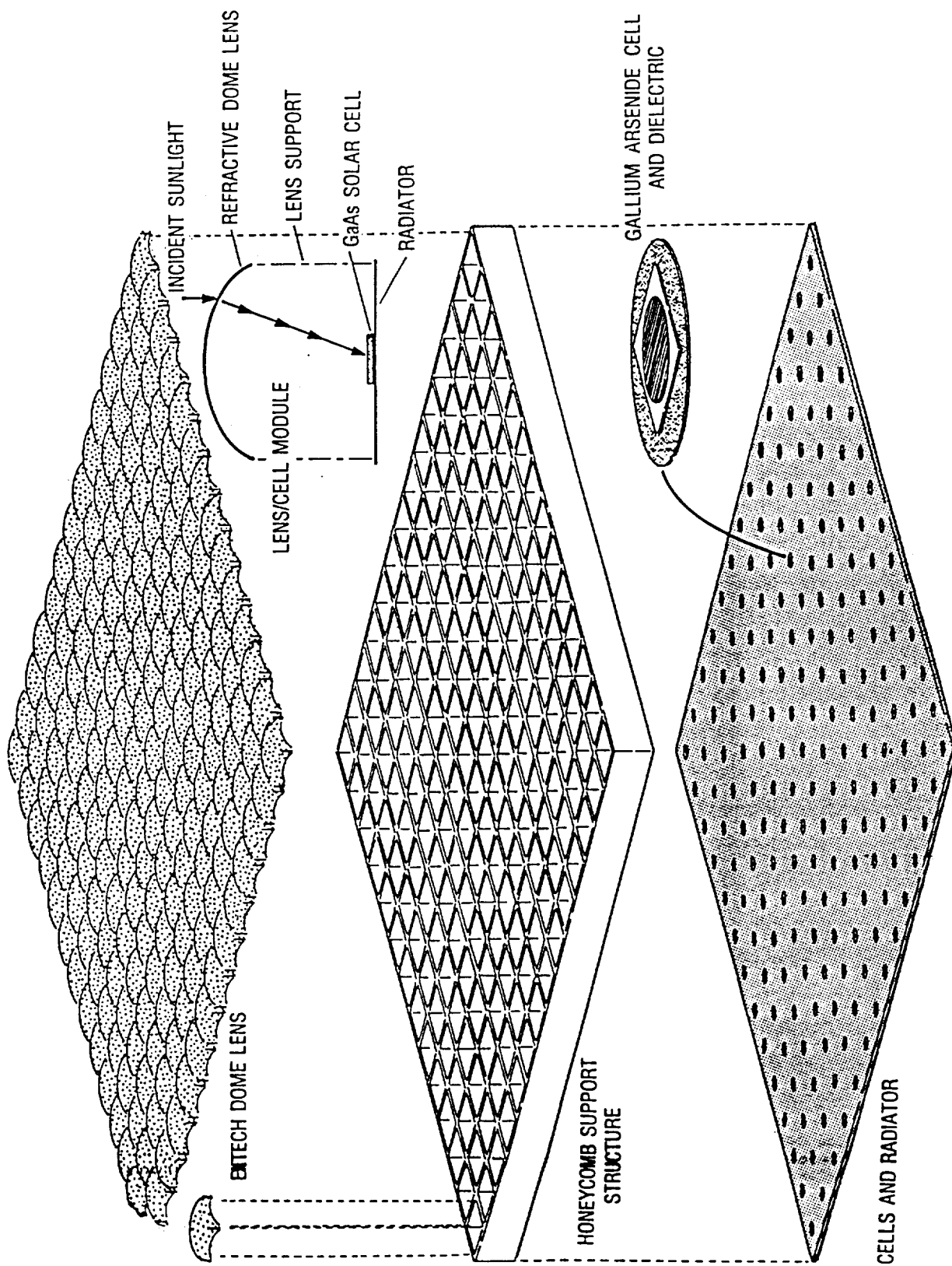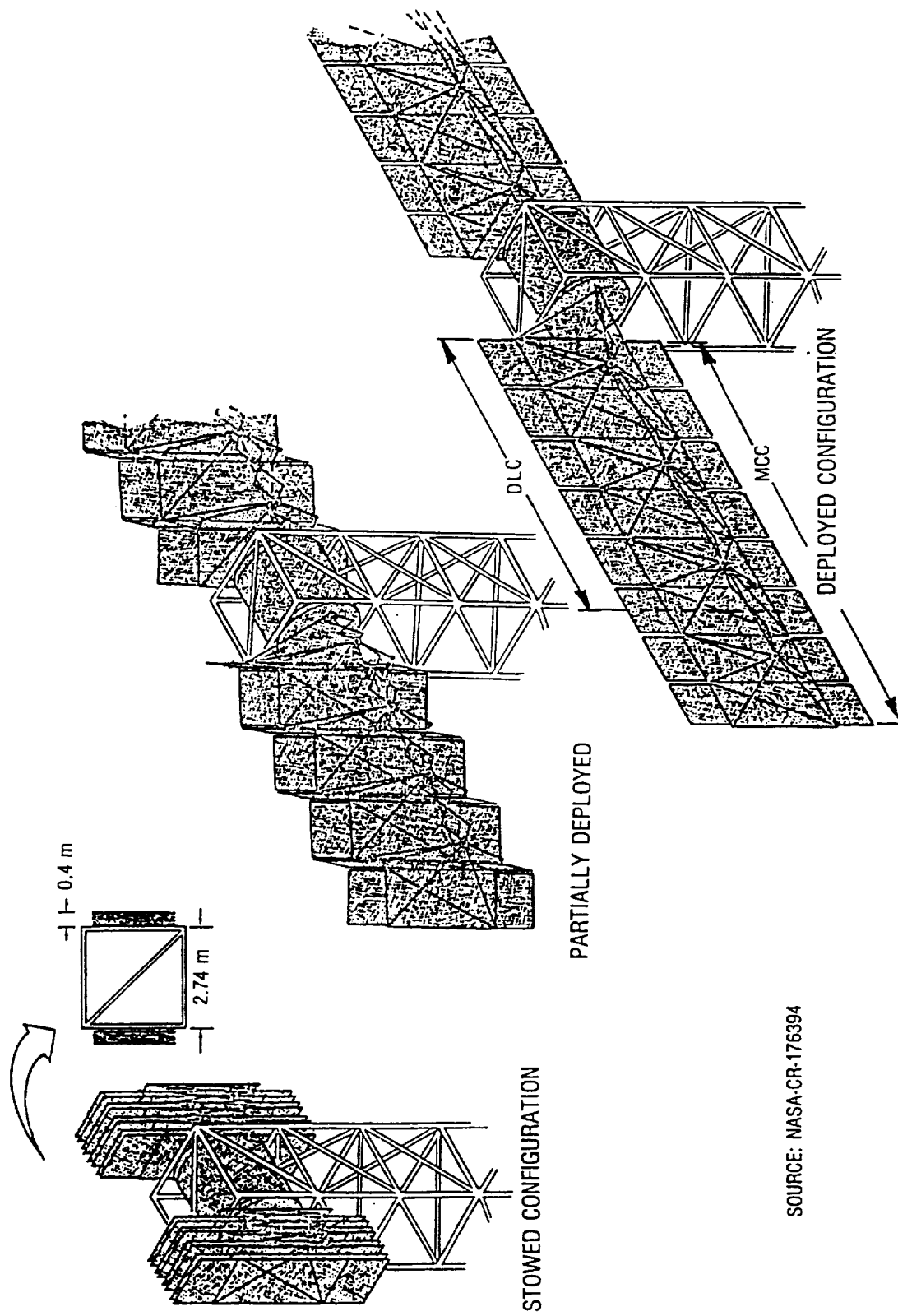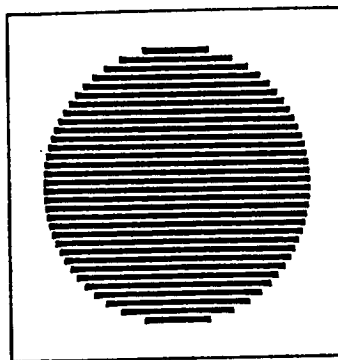
Fig. 1 – Mini-Dome Lens Concentrator Module

DOME FRESNEL LENS

SIDES

CELL COVER

TOP CONTACT

CELL

BOTTOM CONTACT

SOLDER

DIELECTRIC

RADIATOR

Fig. 2 – Mini-Dome Lens Concentrator Panel

INCIDENT SUNLIGHT

REFRACTIVE DOME LENS

LENS SUPPORT

GaAs SOLAR CELL

RADIATOR

LENS/CELL MODULE

GALLIUM ARSENIDE CELL AND DIELECTRIC

ENTECH DOME LENS

HONEYCOMB SUPPORT STRUCTURE

CELLS AND RADIATOR

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C-6

Fig. 3 - Mini-Dome Lens Concentrator Array

0.4 m

2.74 m

STOWED CONFIGURATION

PARTIALLY DEPLOYED

DLC

MCC

DEPLOYED CONFIGURATION

SOURCE: NASA-CR-176394

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Fig. 4 – ENTECH/Varian GaAs Cell

GEOMETRY
TOTAL AREA: SQUARE, 0.5 CM PER SIDE.
ACTIVE AREA: CIRCLE, 0.4 CM DIAMETER.

METALLIZATION GRIDLINES: 31 PARALLEL LINES ON 127 MICRON CENTERS, EACH 12 MICRONS WIDE BY 5 MICRONS TALL.

BUSBAR: CONTINUOUS AROUND CELL PERIPHERY.

PREDICTED VS. MEASURED CELL PERFORMANCE AT STANDARD TEST CONDITIONS

(100 UNIFORM AM0 SUNS, 25C CELL TEMPERATURE)

PARAMETER	PREDICTED VALUE	NASA-MEASURED VALUE
SHORT-CIRCUIT CURRENT:	0.415 AMP	0.423 AMP
OPEN-CIRCUIT VOLTAGE:	1.154 VOLTS	1.143 VOLTS
FILL FACTOR:	87.5 %	86.1 %
CELL EFFICIENCY:	24.3 %	24.2 %

PREDICTED VS. MEASURED CELL EFFICIENCY AT ORBITAL OPERATING TEMPERATURE

(100 UNIFORM AM0 SUNS, 100C CELL TEMPERATURE)

PREDICTED CELL EFFICIENCY: 21.7%
NASA-MEASURED CELL EFFICIENCY: 21.9%

Fig. 5

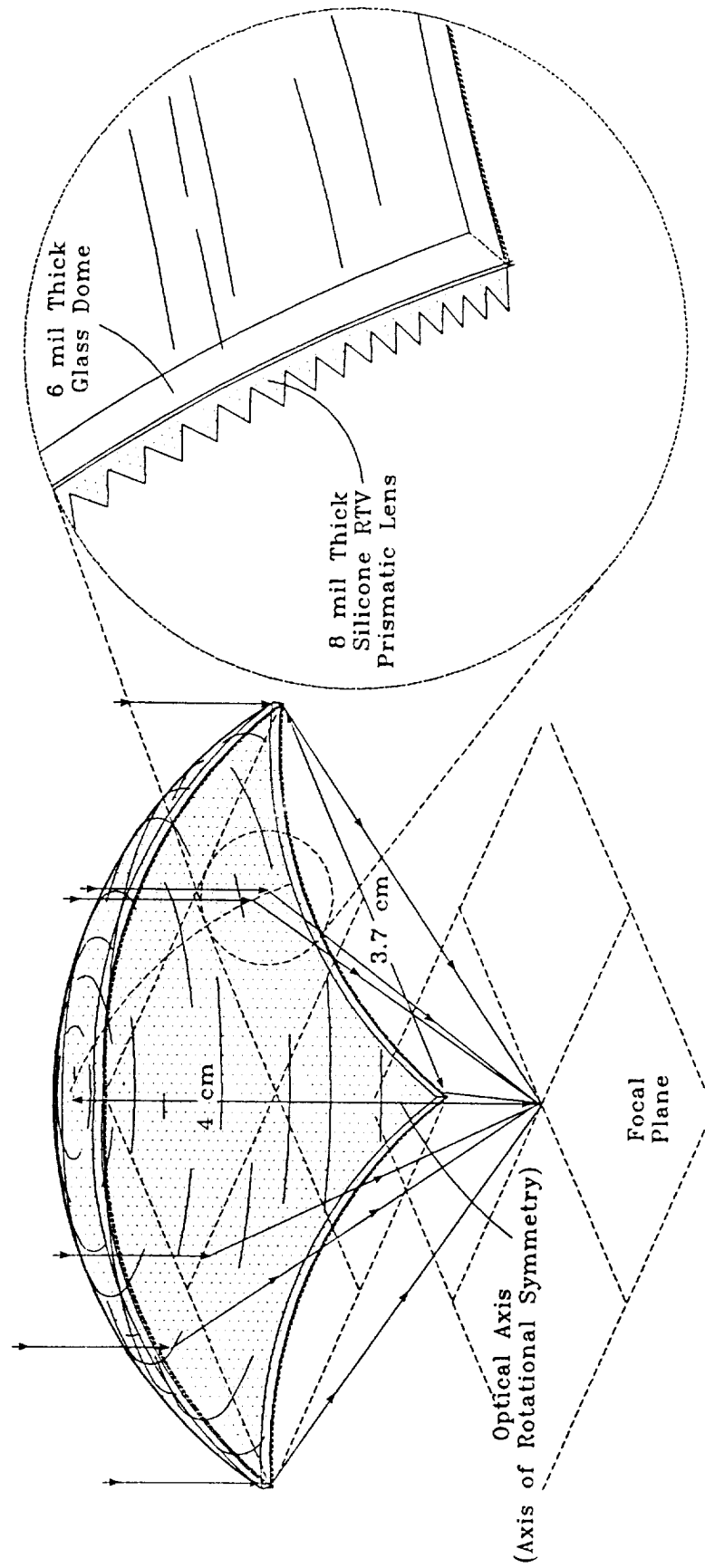LAMINATED CERIA MICROGLASS/SILICONE RTV
MINI-DOME FRESNEL LENS

6 mil Thick
Glass Dome

8 mil Thick
Silicone RTV
Prismatic Lens

3.7 cm

4 cm

Optical Axis
(Axis of Rotational Symmetry)

Focal
Plane

Fig. 6 - Lens Design Approach and Predicted Performance

NUMERICAL RESULTS

IRRADIANCE OVER 0.40 CM SQUARE

1	1	0	0	0	1	0	2
1	0	6	53	67	10	4	1
1	8	170	150	277	287	13	1
0	63	286	253	274	309	93	0
0	86	312	299	273	326	78	0
1	12	332	391	258	178	9	0
0	4	15	97	82	9	1	1
0	1	0	0	0	1	2	0

4000 RAYS OUT OF 4000
OPTICAL EFFICIENCY TO ACTIVE AREA = .933

4000 RANDOM RAY INTERCEPTS
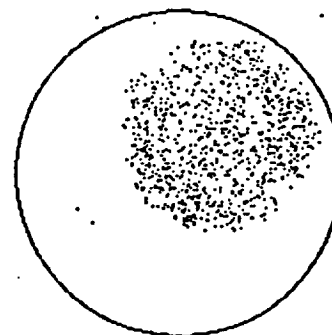(ACTIVE AREA CIRCLE DIAMETER = 0.4 CM)
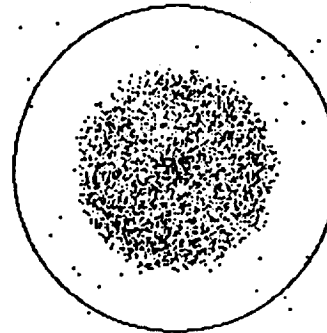
No Tracking Error

NUMERICAL RESULTS

IRRADIANCE OVER 0.40 CM SQUARE

0	0	10	5	57	72	15	5
0	0	31	117	164	303	205	10
0	0	67	281	186	269	365	98
0	0	67	349	295	263	400	87
0	5	15	307	431	210	142	5
0	5	0	10	119	113	15	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

1000 RAYS OUT OF 1000
OPTICAL EFFICIENCY TO ACTIVE AREA = .934

1000 RANDOM RAY INTERCEPTS
(ACTIVE AREA CIRCLE DIAMETER = 0.4 CM)

1 Degree Tracking Error
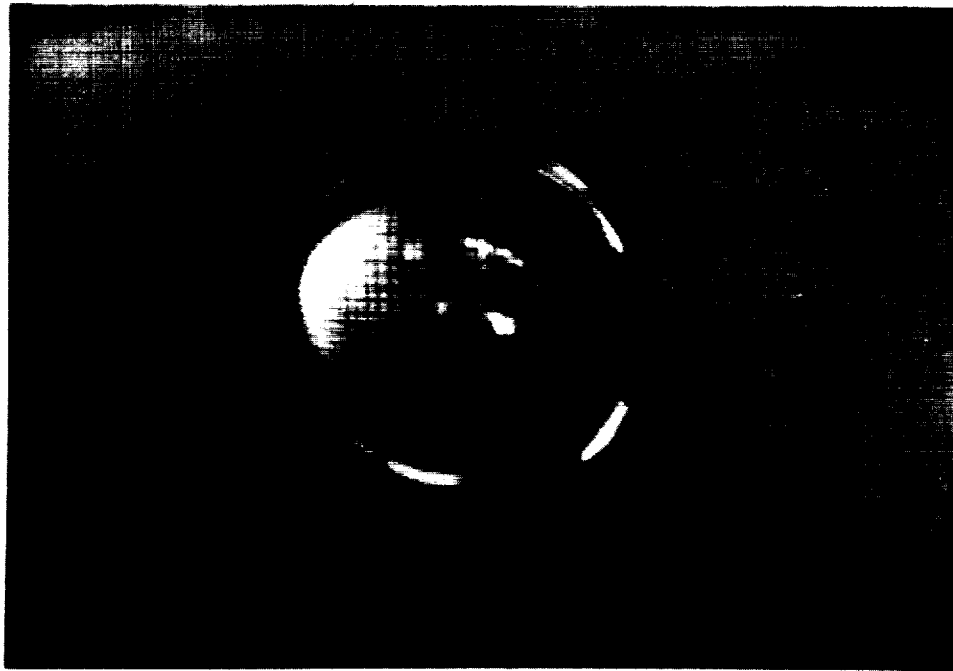
Fig. 7 - Prototype Silicone Rubber Lens

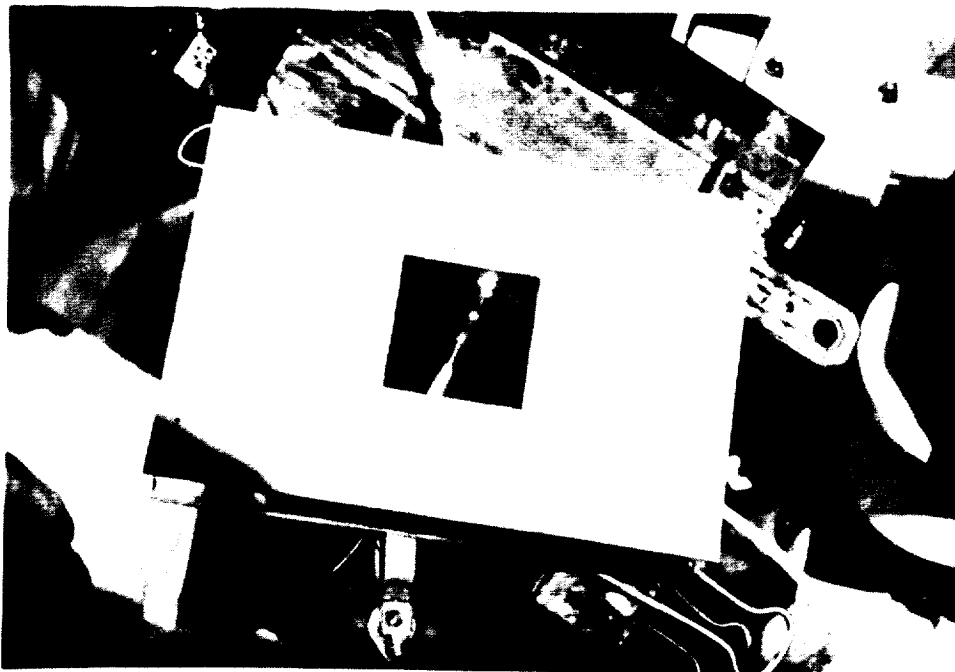Fig. 8 - Prototype Lens Focussing on Cell

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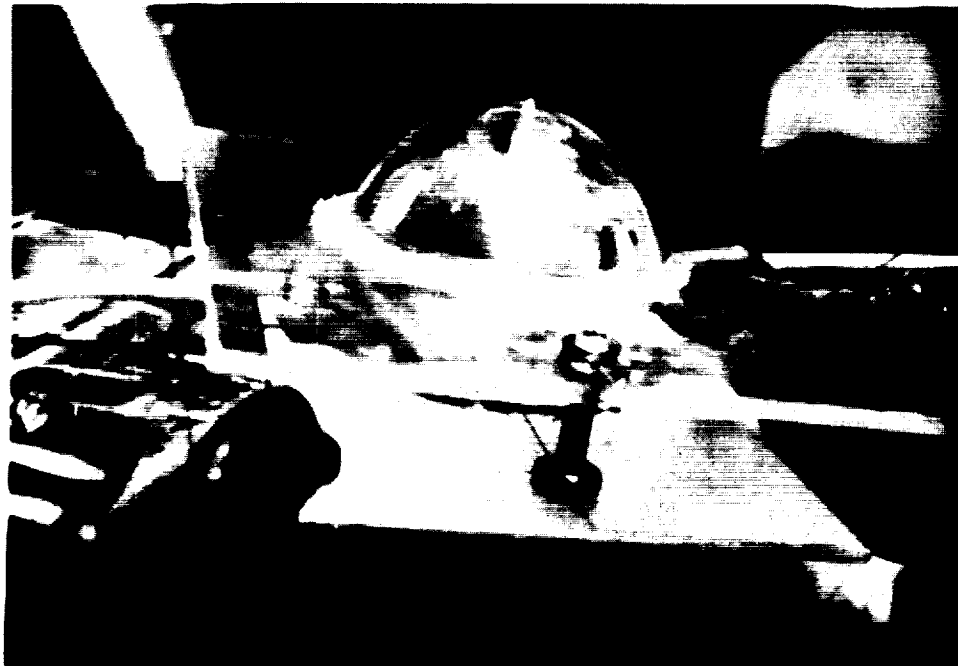
Fig. 9 - Square Aperture Mask for Prototype Lens

Fig. 10 - Square Aperture Lens Focussing on Cell

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TEST DESCRIPTION	LENS APERTURE AREA (SQ.CM.)	CELL ACTIVE AREA (SQ.CM.)	GCR	ISC* (MA)	NCR (SUNS)	OPTICAL EFFICIENCY
ONE-SUN RESPONSE	N/A	0.126	1X	2.92*	1	100%
FULL DOME LENS						
USING 5.4 CM DIAMETER HOLE AREA IN LENS MOUNTING PLATFORM	22.9	0.126	182X	451*	154	85%
USING 5.5 CM DIAMETER TOTAL LENS APERTURE AREA	23.8	0.126	189X	451*	154	81%
MASKED SQUARE LENS	13.7	0.126	109X	274*	94	86%
(3.7 CM X 3.7 CM)						

* NORMALIZED TO 1000 W/SQ.M. DIRECT NORMAL INSOLATION.

Fig. 11 - Summary of Outdoor Test Results for Silicone Mini-Dome Fresnel Lens and 1985-Vintage ASEC GaAs Cassegrainian Concentrator Cell

Element	Material	Density (g/cu.cm.)	Thickness (cm)	Surface Area/Panel Area	Mass/Panel Area (kg/sq.m.)
Lens Superstrate	Microglass	2.50	0.015	1.30	0.49
Lens Prisms	Silicone	1.00	0.015*	1.30	0.19
Radiator	Aluminum	2.77	0.020	1.00	0.55
Cell/Cover/Mount	GaAs et al	5.70	0.046	0.02	0.05
Honeycomb	Aluminum	2.77	0.015	2.20	0.91
Radiator Coating	Alumina	3.88	0.001	2.00	0.08
Miscellaneous			7.5% of Above Total		0.17
TOTAL					2.44

* Silicone Base Thickness = 0.010 cm
Silicone Prism Thickness = 0.010 cm (But Half Void)
Effective Silicone Thickness = 0.015 cm

Fig. 12 - Mass Breakdown for Baseline Mini-Dome Lens Panel

Fig. 13

MINI-DOME FRESNEL LENS ARRAY - UPDATED PERFORMANCE ESTIMATES
BASED ON RECENT TEST RESULTS FOR PROTOTYPE CELLS AND LENSES

ITEM	BASELINE ARRAY	NEAR-TERM ARRAY	LONGER-TERM ARRAY
CELL TYPE	GaAs	GaAs + GaSb	GaAs + GaSb
CELL EFF. AT 25C	24%	24% + 8% = 32%	24% + 9% = 33%
CELL OPERATING TEMP.	100C	100C & 100C	130C & 130C
CELL EFF. AT OPER. TEMP.	22%	22% + 6% = 28%	21% + 6% = 27%
LENS EFFICIENCY	86%	86%	90%
PACKING FACTOR	97%	97%	97%
MISMATCH/WIRING FACTOR	93%	93%	93%
ARRAY EFFICIENCY	17%	22%	22%
POWER DENSITY (W/SQ.M.)	230	300	300
PANEL MASS (KG/SQ.M.)	2.4	2.4	1.0
STRUCTURE MASS (KG/SQ.M.)	0.7	0.7	0.4
ARRAY MASS (KG/SQ.M.)	3.1	3.1	1.4
SPECIFIC POWER (W/KG)	74	97	214

NOTE: MEASURED PERFORMANCE PARAMETERS FOR PROTOTYPE CELLS AND LENSES ARE UNDERLINED.

Workshop Summaries

Mechanical vs. Monolithic Multijunction Cells

John Fan

Kopin Corporation
Taunton, MA

WORKSHOP 1

MECHANICAL vs. MONOLITHIC MULTIJUNCTION CELLS

1. **WHAT IS KNOWN ABOUT RADIATION DAMAGE IN THE TWO TYPES OF CELLS?**

   - MORE RADIATION DAMAGE DATA NEEDED

   - NEED SPECTRAL RESPONSE AS FUNCTION OF RADIATION DAMAGE

   - NEED MORE PROTON DAMAGE DATA

2. **HOW MANY TERMINALS CAN BE USED - 2, 3, OR 4?**

   - DESIGNS FOR 2, 3, OR 4 EXIST AND ARE REASONABLE

   - NEED A TERM FOR THE SOLAR CELL ASSEMBLY SUCH AS PV ELEMENT

   - VOLTAGE - MATCHING LOOKS LIKE A VERSATILE APPROACH

3. **WHAT ARE THE ISSUES WITH AR COATINGS AND/OR OPTICAL COUPLING?**

   - MORE COMPLICATED FOR MECHANICAL STACK

   - TRADE-OFF FOR EASIER EPITAXY

WORKSHOP 1

MECHANICAL vs. MONOLITHIC MULTIJUNCTION CELLS

4. **IS THERE A PREFERRED CONFIGURATION - (PLANAR, CONCENTRATOR MONOLITHIC OR MECHANICAL STACK, 2, 3, OR 4 TERMINALS)**

   - PV ELEMENT TERMINALS SHOULD BE 2

   - PLANAR vs CONCENTRATOR TOO SOON TO TELL

   - MONOLITHIC vs MECHANICAL: MONOLITHIC, LATTICE-MATCHED SYSTEM MAY BE PREFERABLE IN LONG TERM

   - IT IS NOT CLEAR THAT A MONOLITHIC APPROACH OFFERS HIGHER SPECIFIC POWER

   - THERE ARE THERMAL ISSUES IN MECHANICALLY STACKED CONCENTRATORS

5. **WHAT IS KNOWN ABOUT TEMPERATURE EFFECTS? WHAT WORK NEEDS TO BE DONE?**

   - CONCENTRATION RATIO, TEMPERATURE HAVE A BIG EFFECT ON MEASURMENTS

   - SPECTRAL RESPONSE CURVES AT APPROPRIATE TEMPERATURE IS IMPORTANT

   - BIGGER PROBLEM IS THE LACK OF PROPER SIMULATOR

WORKSHOP 1

MECHANICAL vs. MONOLITHIC MULTIJUNCTION CELLS

6. **WHAT SHOULD BE DONE ABOUT TESTING MBG CELLS? ARE SIMULATOR RESULTS RELIABLE?**

   - FULL SPECTRUM SIMULATORS ARE NEEDED
   - CALIBRATION STANDARDS ARE NECESSARY
   - NASA SHOULD BE PLANNING A CALIBRATION STANDARDS PROGRAM FOR MBG CELLS
   - NEED CENTRAL PLACE FOR RELIABLE TESTING

7. **WILL THERE BE OR ARE THERE PRODUCTION YIELD PROBLEMS SPECIFIC TO MBG CELLS?**

   - MAYBE FOR LATTICE MISMATCHED MONOLITHIC APPROACHES
   - LATTICE-MATCHED AND MECHANICAL STACK APPROACHES HAVE YIELD ISSUES THAT ARE DIFFERENT BUT ABOUT THE SAME LEVEL OF DIFFICULTY.

WORKSHOP 1

MECHANICAL vs. MONOLITHIC MULTIJUNCTION CELLS

8. **WHAT ARE PROJECTED COSTS (PER WATT) FOR VARIOUS TYPES?**
   - TOO SOON TO ANSWER

9. **WHAT ARE THE ARRAY/SYSTEM LEVEL BENEFITS AND ISSUES? ARE THERE WEIGHT AND AREA ADVANTAGES?**
   - IF EFFICIENCY IS REALIZED, YES
   - TOO SOON TO TELL WHETHER MONOLITHIC IS BETTER THAN MECHANICAL STACK

10. **ARE ULTRA LIGHT WEIGHT THIN FILM MBG CELLS FEASIBLE**
   - NEED TO DEFINE ULTRA LIGHT WEIGHT
   - 200 W/kg IN 5 YRS. FOR ARRAY LOOKS FEASIBLE
   - 750 W/kg IN 2 YRS. FOR CELLS LOOKS FEASIBLE

PV ELEMENT
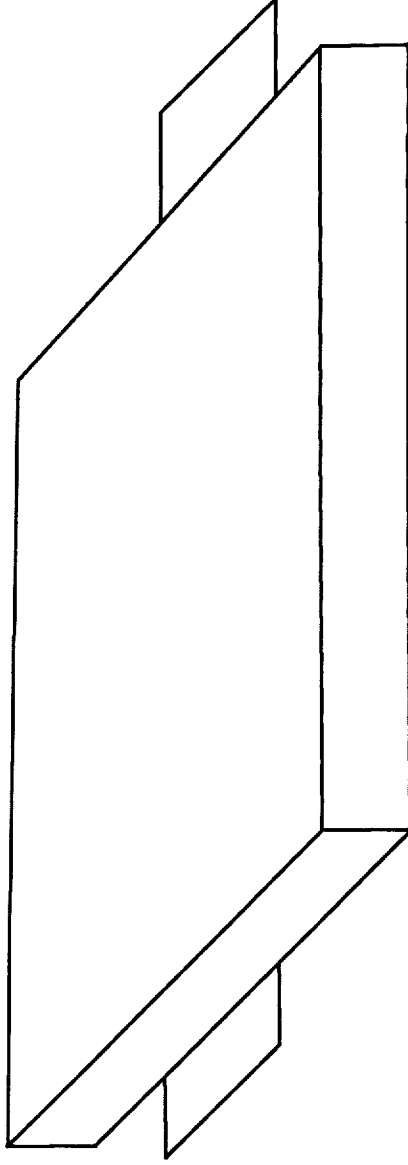
- ABOUT SAME SIZE AS A CELL

- WELL-KNOWN CHARACTERISTICS (SPEC'S)

- FITS INTO ARRAY "SOCKET"

- INTERNAL PARTS NOT SPECIFIED EXPLICITLY